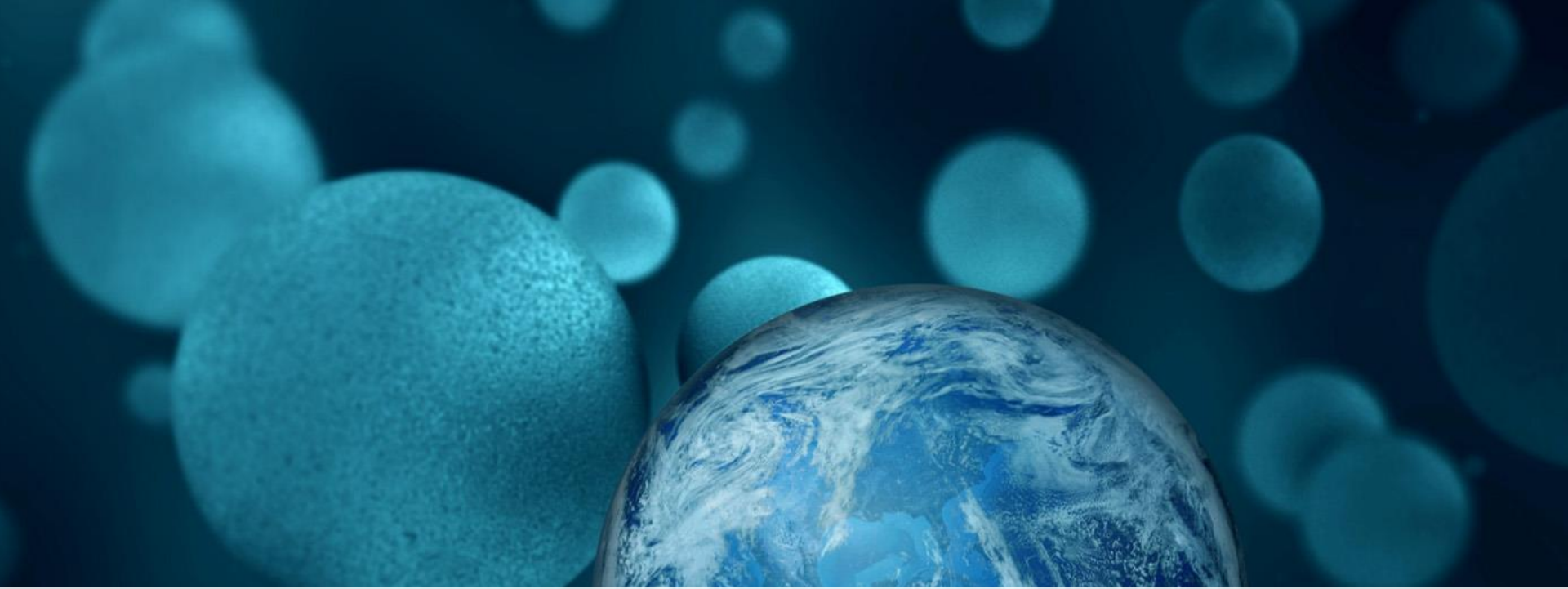

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RadEye HEC+ Training and Workshop

(edited with clarifications Nov 21, 2022)

Michael Iwatschenko-Borho, Nov 8, 2022

michael.iwatschenko@thermofisher.com

Morning Session: Powerpoint with discussion and interaction

Basic features of the RadEye HEC+ sample changer & Specifics of the detector
NEW (hardware upgrade possible): Reduced sensitivity to high energy gamma background

Basic application modes (Beta/Alpha & EC-mode) – when to use which mode
Calculation of average beta energy (EC) – discussion of use cases
Application discussion (plant mix, outages, decommissioning)

Optional customized energy window settings for known single isotopes (e.g. source wipe tests)
Optional customized usage of calibration factors and window settings for mixed contamination

NEW (planned firmware option): Rn-compensation for Beta/Alpha & EC-mode

User Interface / useful features

What to avoid, maintenance, field calibration checks and trouble-shooting

Supporting PC-software, firmware update, accessories and spare parts

Afternoon Session: Practical training and interaction

Measurement of various check sources, test-adapters and air filters (Rn compensation)

Discussion of user interface, suggestions for improvement etc.

End of general session

Bonus session:

Special tritium workshop and discussion

RadEye HEC+ Sample Changer (up to 60 mm Filters)

- 2“ windowless detector (ZnS(Ag) / plastic)
- Low noise PMT
- 4 kg, 1000 h battery life (NiMH)

➔ Designed for work place monitoring

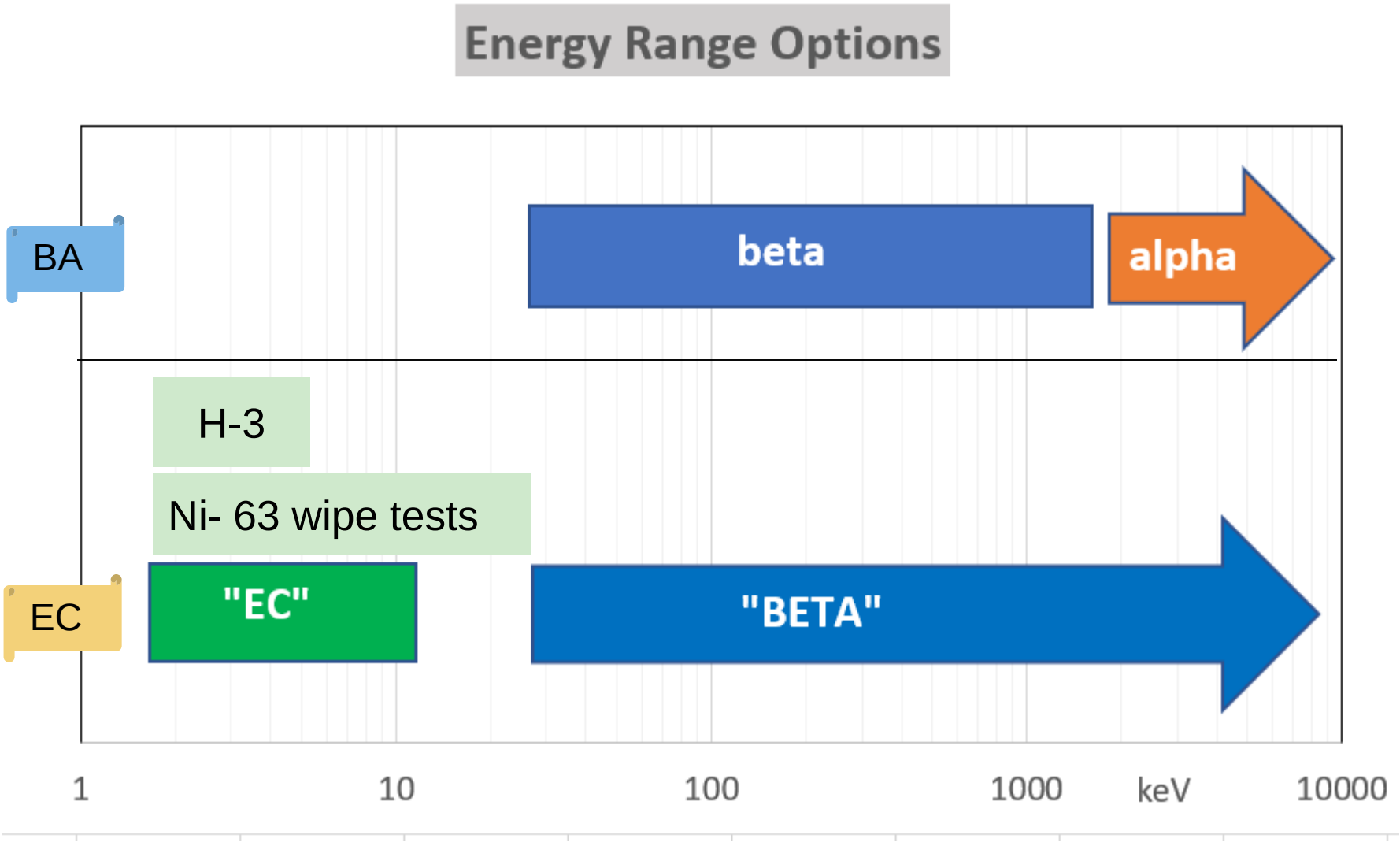
2 Operation Modes:

a) Classic Beta/Alpha Mode (BA-mode)

b) Additional new EC-Mode:

- Includes range 3 keV … 15 keV (X-rays)
- Calculation of mean beta energy

RadEye HEC+: 2 Modes („Applications“) BA & EC



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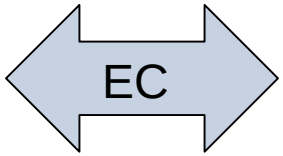
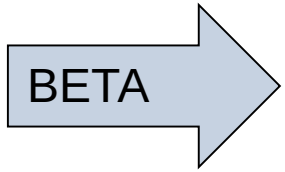
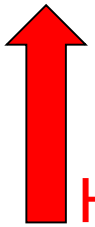
Settings EC - Mode



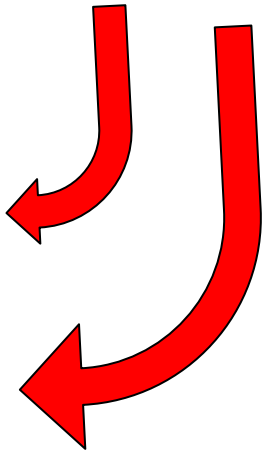


EC-mode thresholds (mV): 40 – 160* – **2200** - 260



HE–indicator

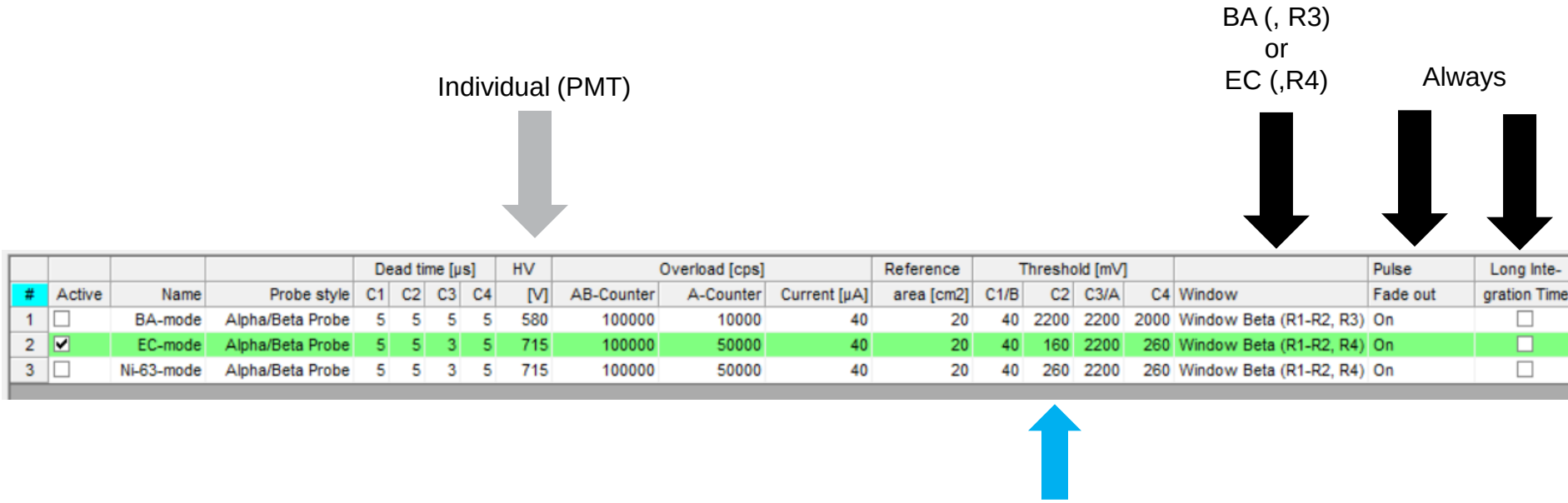
*: default (best energy calculation)
(260 mV Ni-63 wipe tests)
(100 mV H-3 wipe tests)



Mean energy calculation

Dead time correction for EC-channel & overload warning once too many high energy events disturb the EC-channel

Application Settings in RadEye.EXE



				Dead time [µs]				HV	Overload [cps]			Reference	Threshold [mV]					Pulse	Long Inte-
#	Active	Name	Probe style	C1	C2	C3	C4	[V]	AB-Counter	A-Counter	Current [µA]	area [cm2]	C1/B	C2	C3/A	C4	Window	Fade out	gration Time
1	☐	BA-mode	Alpha/Beta Probe	5	5	5	5	580	100000	10000	40	20	40	2200	2200	2000	Window Beta (R1-R2, R3)	On	☐
2	☑	EC-mode	Alpha/Beta Probe	5	5	3	5	715	100000	50000	40	20	40	160	2200	260	Window Beta (R1-R2, R4)	On	☐
3	☐	Ni-63-mode	Alpha/Beta Probe	5	5	3	5	715	100000	50000	40	20	40	260	2200	260	Window Beta (R1-R2, R4)	On	☐

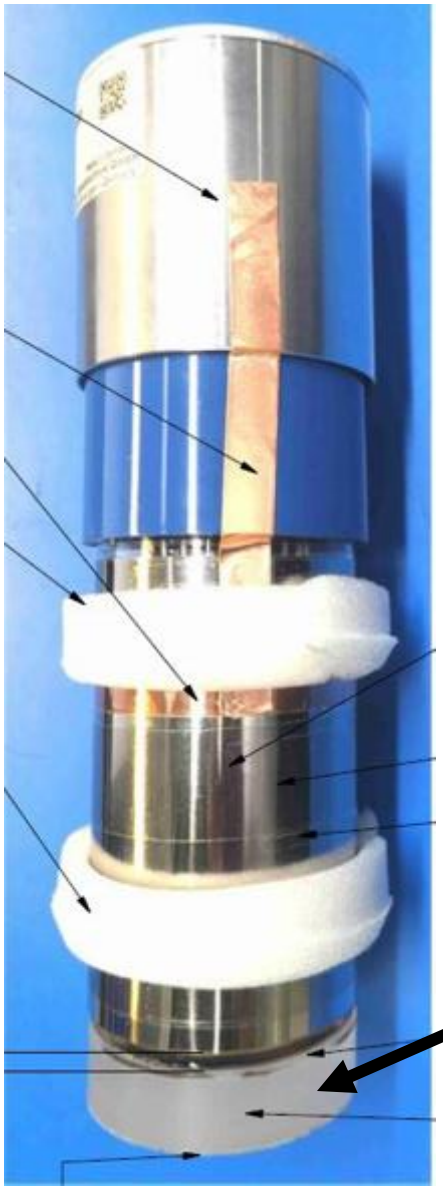
Ni-63-Mode: **EC-**Efficiency improvement app. + 50 % (Ni-63, C-14),
due to wider EC-window,
Background increase app. + 20 %
Improved (reduced) detection Limit 27 %

Remark 1: High voltage for all EC-mode applications is typically 23 - 25 % higher than for BA-mode

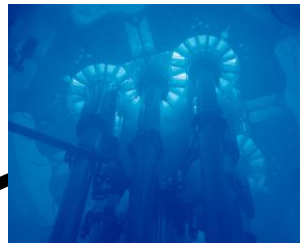
Remark 2: Mean energy calculation is best for standard EC-mode setting

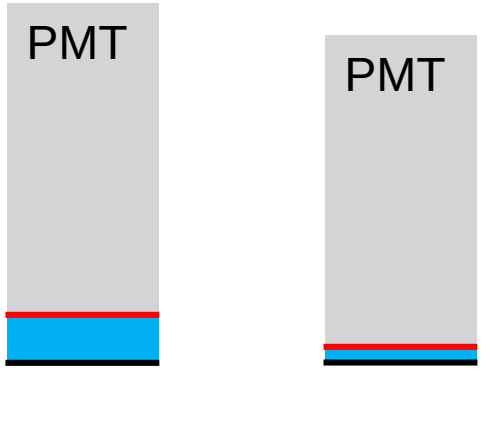
Remark 3: Reduction of threshold R2 in the BA-mode (upper limit of beta-window) can be used to match sensitivity of e.g. Co-60 and Sr/Y-90.

HEC+ Detector & Cherenkov-Background Improvement



Wanted Sensitivity	Unwanted Sensitivity
Alpha	Light
Beta	Muons
X-rays	Gamma





Old Light Guide:	12,5 mm	
New light guide:	1,5 mm	
Background Reduction	Co-60	Th-232 (NORM)
EC	-62%	-53%
Beta	-7%	-22%

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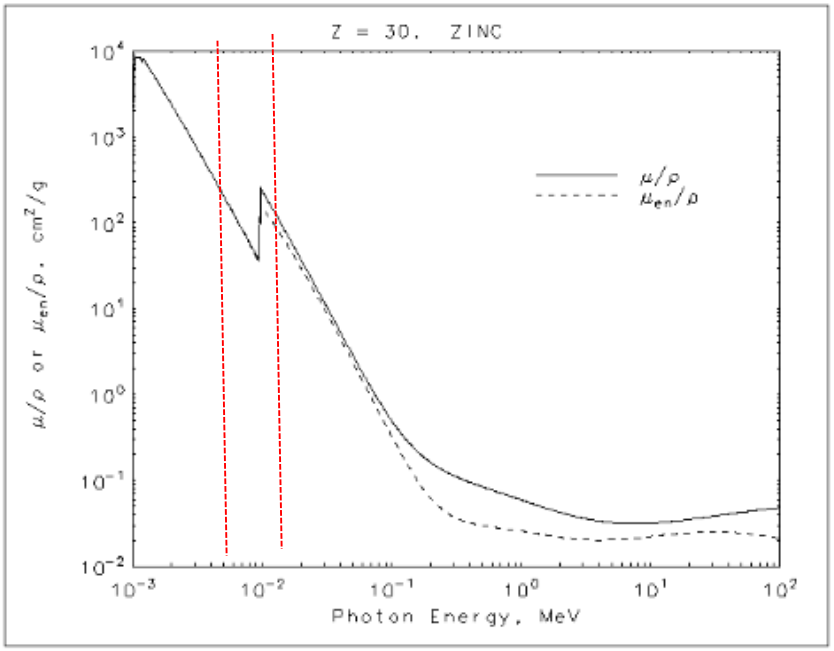
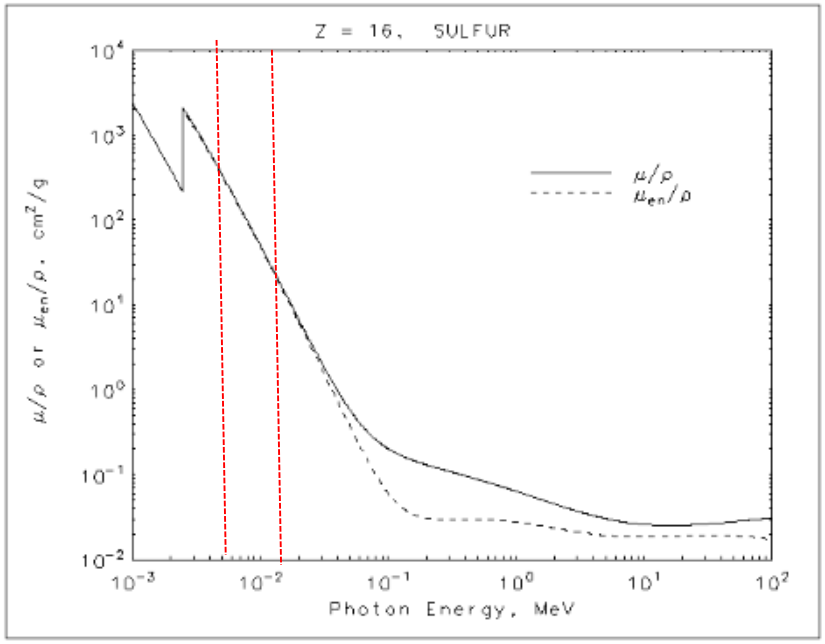
X-Ray Sensitivity in the EV-Mode

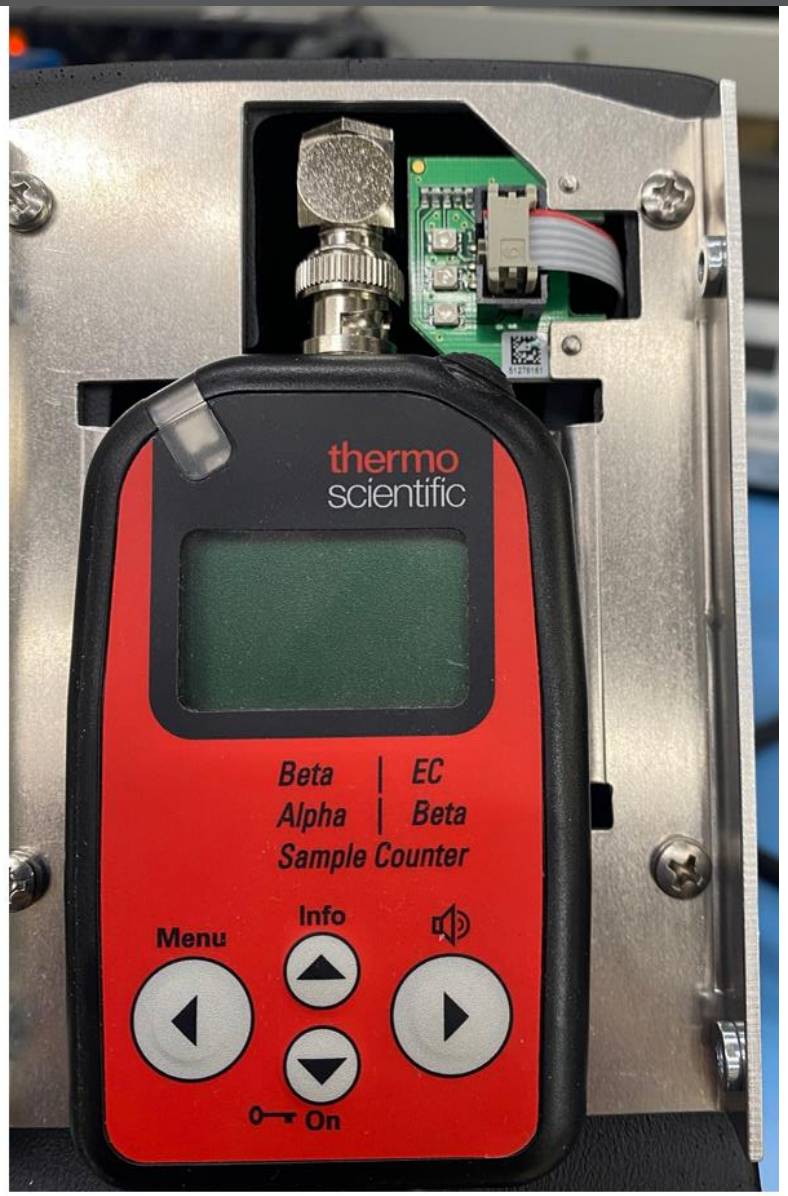




Both Zn and S contribute about equally
to the absorption at around 6 keV (Fe-55),

but Zn works nicely between 10 keV and 15 keV as well!

Cover (removable by 4 screws)



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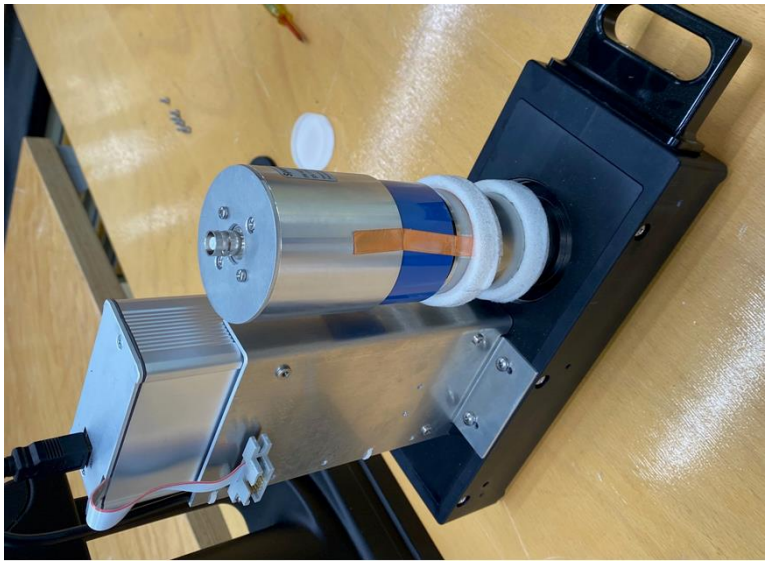
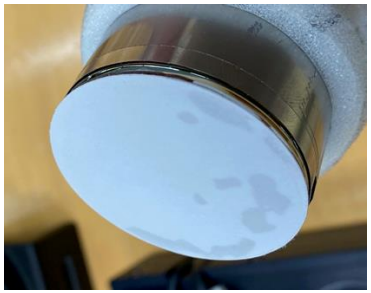
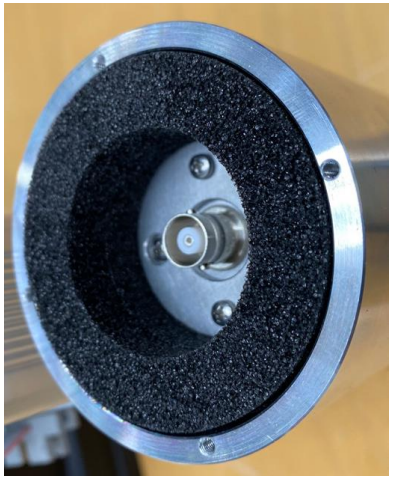
Exchange of Phosphor / Light Guide



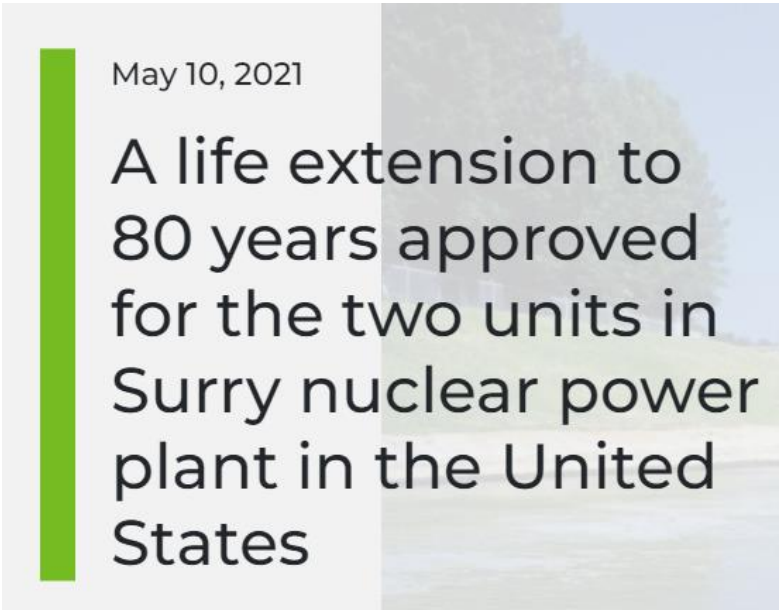




Benefits of EC-Mode for Measuring Activation Products

Category	Nuclide	Half-life (a)	Beta mean (keV)	Beta max (keV)	X-rays	Industrial/ Medical Usage	Beta Survey Meter	Dual Phosphor DP6+ (EC)	Windowless Dual Phosphor RadEye HEC+
Tritium et al.									
	H-3	12	6	18		x			(*)
	Mo-93	3.500	15	15					*
	Pd-107	6.500.000	9	33					*
EC or IT									
	Nb-93m	16	28	28	10%		(*)	*	**
	Fe-55	3			27%	x	*	**	**
	Ni-59	75.000			34%		*	**	**
Ni-63 class									
	Ni-63	100	17	67		x	*	**	***
	Zr-93	1.500.000	20	62			*	**	***
	Sm-151	89	25	76			*	**	***
C-14 class									
	C-14	5.700	50	156		x	**	***	***
	S-35	0,2	49	167		x	**	***	***
	Se-79	65.000	52	149			**	***	***
	I-129	16.000.000	55	150			**	***	***

More Neutron Activation Products with Long Half Life…

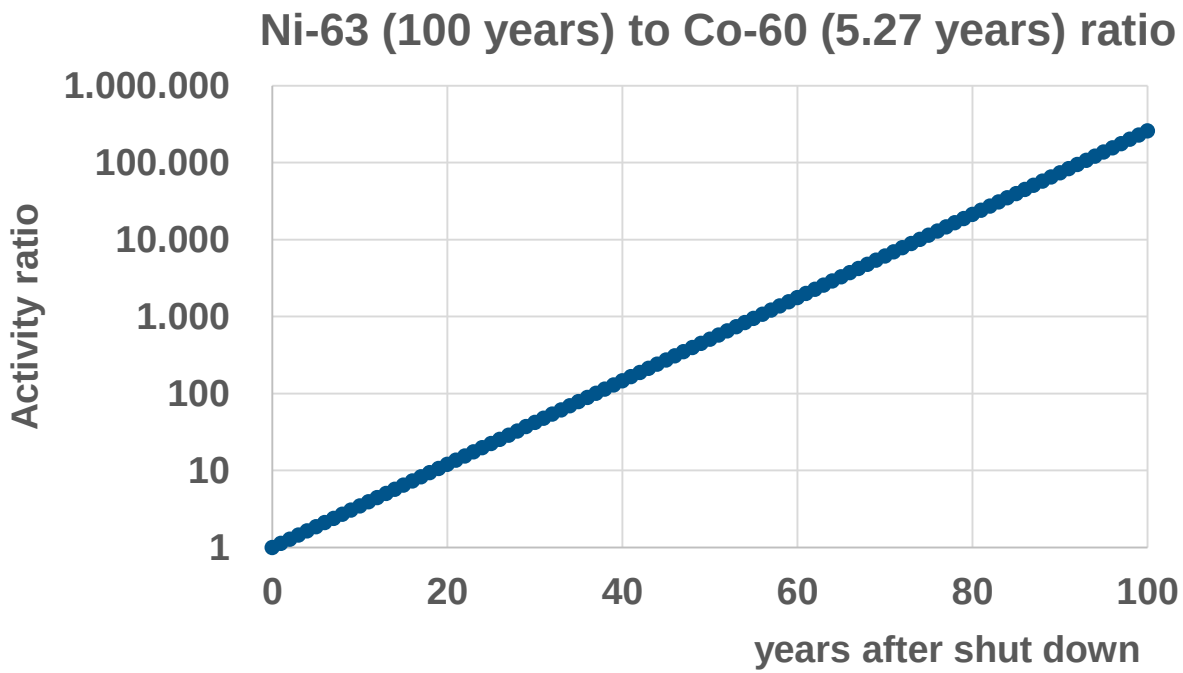


France extends lifetime of its oldest nuclear reactors

By SYLVIE CORBET February 25, 2021

PARIS (AP) — France's nuclear safety authority agreed Thursday to extend the operational lifetime of the country's 32 oldest nuclear reactors by a decade to as much as 50 years.

Time since Shut Down: Impact on Activation Product Ratio



Using a Co-60 correlation coefficient can become difficult:

Correlation Coefficients (Literature) vary by 4 orders of magnitude…
(PWR versus BWR, Co and Ni content in the steel, …)

Activation Nuclide Inventory after Shutdown (BWR)

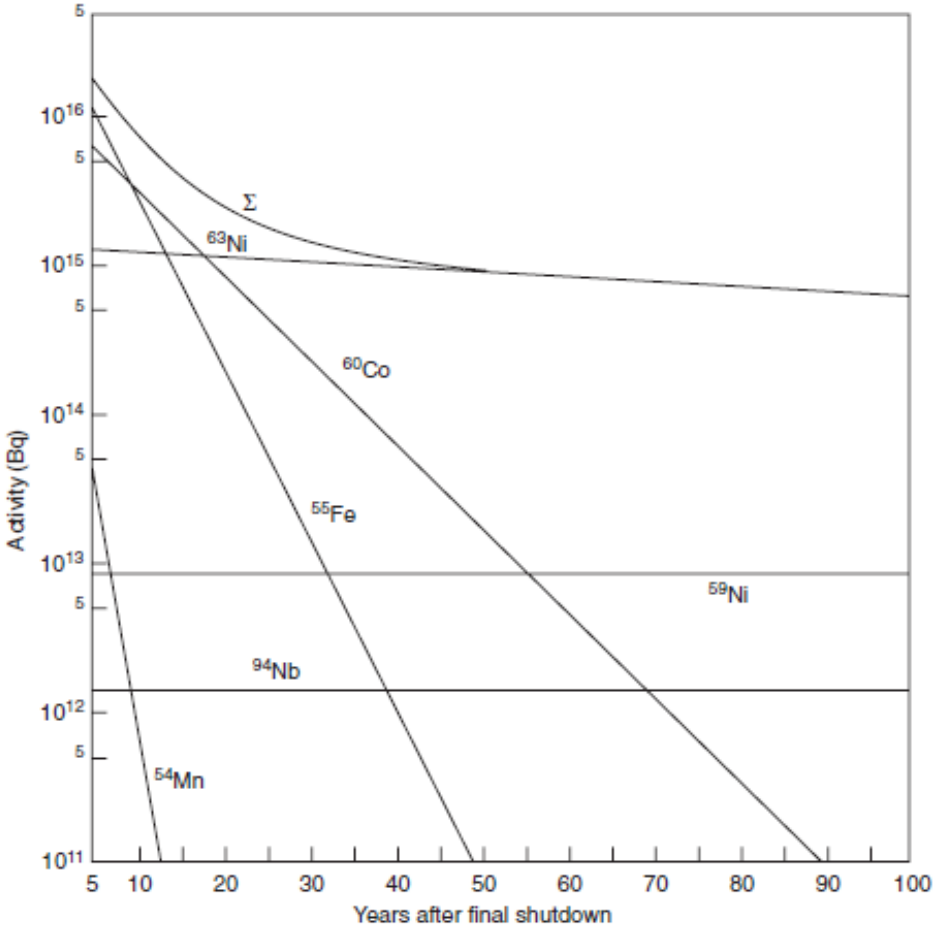


FIG. 2. Calculated decay of principal radionuclides of the reactor pressure vessel (Lingen BWR) [7].

Source: „Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purposes“, IAEA 1998

Activation Nuclide Inventory after Shutdown (Magnox)

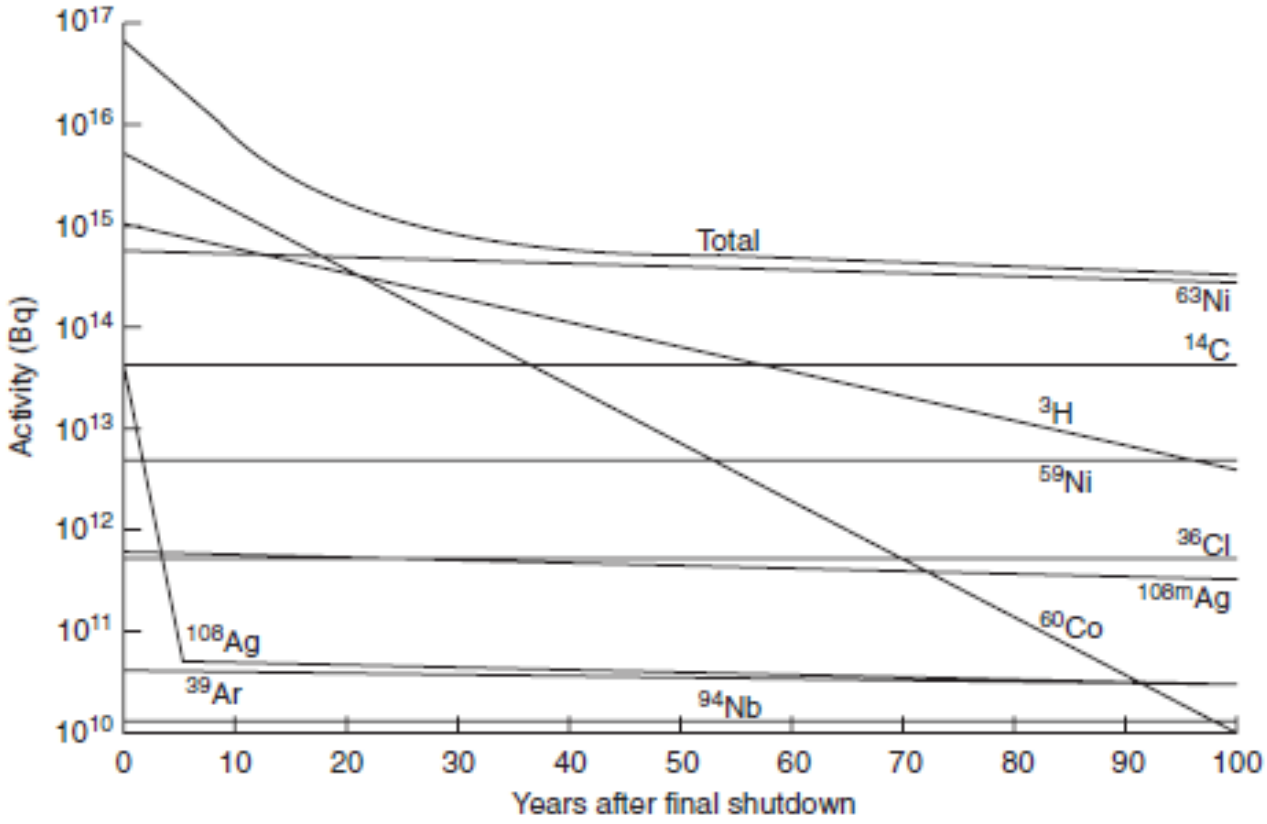


FIG. 4. Calculated decay of principal radionuclides (Latina NPP).

Source: „Radiological Characterization of Shut Down Nuclear Reactors for Decommissioning Purposes“, IAEA 1998

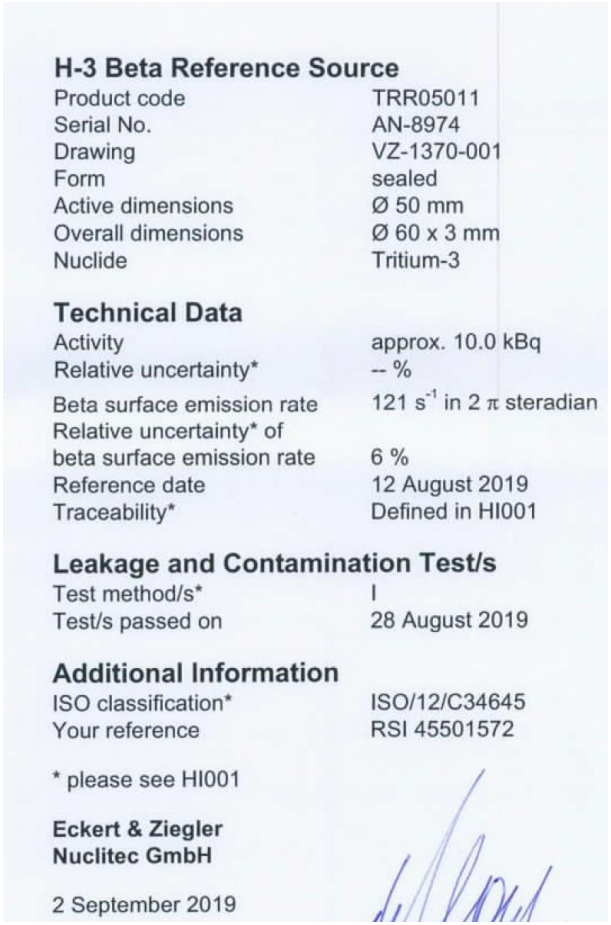
UK-Type Test Data of RadEye HEC+ (50 mm dia. Sources)

4 Pi Efficiency	BA-Mode		EC-Mode	
	Beta	Alpha	"EC"	"BETA"
Ni-63	1,5%		16%	1,1%
C-14	14%		16%	14%
Co-60	23%		12%	23%
Cs-137	33%		1,6%	33%
Cl-36	36%		3,9%	36%
Sr/Y-90	35%		4,4%	35%
Am-241	1,2%	39%	0,0%	42%
U-238	39%	38%	13%	47%
Pu-239	0,4%	41%	0,6%	42%
Fe-55			5%	
Mn-54			5%	

Background (cps)	0,7	"0"	0,7	0,7

Even Tritium attached to filter surface can be measured!

Eckert & Ziegler Data (P-factors for Different Beta Energies)



H-3 Beta Reference Source

Product code	TRR05011
Serial No.	AN-8974
Drawing	VZ-1370-001
Form	sealed
Active dimensions	Ø 50 mm
Overall dimensions	Ø 60 x 3 mm
Nuclide	Tritium-3

Technical Data

Activity	approx. 10.0 kBq
Relative uncertainty*	-- %
Beta surface emission rate	121 s^{-1} in 2 π steradian
Relative uncertainty* of beta surface emission rate	6 %
Reference date	12 August 2019
Traceability*	Defined in HI001

Leakage and Contamination Test/s

Test method/s*	I
Test/s passed on	28 August 2019

Additional Information

ISO classification*	ISO/12/C34645
Your reference	RSI 45501572

* please see HI001

Eckert & Ziegler
Nuclitec GmbH

2 September 2019

Nuclide	Nominal activity	Particle emission rate [1/s]
Beta sources		
H-3	10 kBq	100-300
Ni-63	1 kBq	~ 100
C-14	1 kBq	~ 380
Tc-99	1 kBq	~ 490
Co-60	185 Bq	~ 90
	1 kBq	~ 480
	3 kBq	~ 1450
Cs-137	1 kBq	~ 610
Cl-36	1 kBq	~ 630
Sr-90/Y-90[3)]	185 Bq	~ 235

For tritium (and Ni-63) comparison measurements with LSC are recommended, as air filters and wipe tests may show significantly higher 4 Pi response than for commercially available check sources. **Main advantage of RadEye HEC+ in EC-mode is given by the instantaneous indication of a low energy beta contamination without cost and delay.**

Analysis of Beta Spectra: Calculation of Average Energy

In addition to the EC, Beta, Dual display, a 4th screen is accessible that shows additionall information regarding the measured beta contamination:

Info screens for a Ni-63 (17 keV), C-14 (50 keV) and Tc-99 (85 keV) check sources

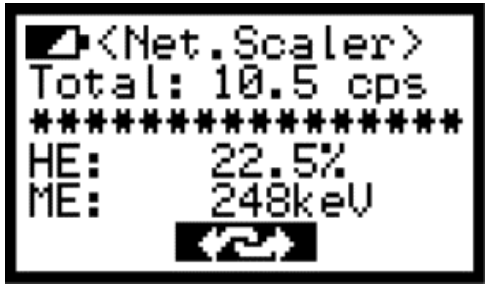
a) Total (net) count rate (cps) including the gap between EC and Beta rate
b) Fraction of high energy events HE (%) relative to the total (net) count rate
c) Estimated mean beta energy ME (6 … 300 keV) of the contamination

Assumptions regarding the kind of beta contamination (expected dominant nuclide) can be verified at the work-place!

Robust Average Energy Calculation (EC-Mode, 20 – 300 keV)

C-14 (example):

K-40 (example):



	Ni-63	C-14	Rb-87	Lu-176	K-40
Nominal Average Energy (keV)	17	49	79	292	522
EC-Mode Result (keV)	27	51	81	186	262
Surface covered with filter (keV)	*NA*	57	88	187	232
Change of measured energy	*NA*	112%	109%	101%	89%
Total count rate loss due to filter	*-100%*	-89%	-65%	-24%	-3%

Simulated dust load (by 8 mg/cm² glass fibre filter on top of check source) causes significant reduction of total count rate, but nearly no influence on derived average beta energy!

Reduction of max. energy compensated by hardening of beta spectrum!

Consecutive Measurements and Application Mode Selection

“Auto restart“ is useful for decay analysis of contamination and for generation of large number of measurements (in order to demomonstrate stability and impact of statistical fluctuations.

Names af the various „applications“ are arbitrary and can be set by the PC-software. Background values are stored for BA-mode and EC-mode seperately. I.e. toggling is possiblewithout new background learning.

However, toggling between **different** EC-modes (here „EC-mode, H-3, Ni-63-mode) is not recommended, since only on set of background values is stored.

Rb-87, Lu-176, K-40: Natural Beta Emitters for Periodic Checks

RbCl: 1g	**Low av. energy beta (79 keV):**	**NEW**	**625 Bq/g**
Lu_2O_3: 5 g	**Medium energy beta and low/medium gamma**	**(since 2008)**	**50 Bq/g**
KCl: 3g	**High energy Beta and Gamma (11%) source)**		**17 Bq/g**

All 50 mm adapters: SER = app. 1 s-1 per cm^2

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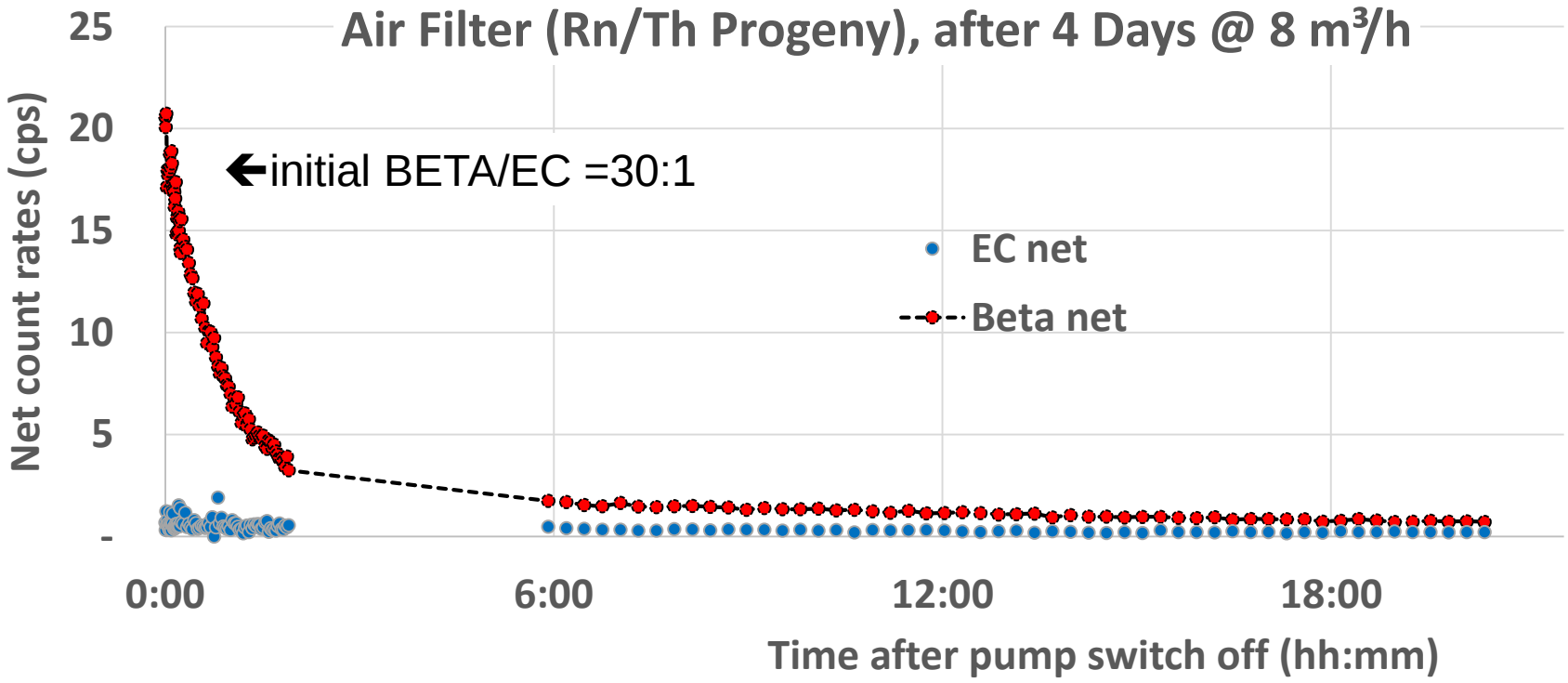
Key Features of Primordial Beta Nuclides

Nuclide	Half-life	Specific activity in the pure isotope	Natural abundance	Specific activity in the natural element	Beta	Gamma	Beta max	Gamma
	Years	Bq/g		Bq/g			kev	kev
In-115	5,1E+14	2,3E-01	95,70%	0,2	100%	0%	495	
La-138	1,1E+11	9,13E+02	0,09%	0,8	33%	100%	253	788-1436
Rb-87	4,8E+10	3,17E+03	27,90%	885,3	100%	0%	273	
Lu-176	3,8E+10	2,09E+03	2,59%	54,1	99%	223%	589	55-307
K-40	1,3E+09	2,59E+05	0,01%	30,3	89%	11%	1312	1460

Part number	Testadapter Description	Primordial Nuclide	Beta mean energy	Specific activity in the compound	Activity Testadapter	SER (beta)	SER (beta)/cm²
			keV	Bq/g	Bq	s^{-1}	s^{-1}/cm^2
42506/7071-25	Testadapter HEC+, 1 g RbCl	Rb-87	79	625	625	22	1,1
42506/7071-21	Testadapter HEC+, 5 g Lu2O3	Lu-176	292	50	250	17	0,85
42506/7071-20	Testadapter HEC+, 3 g KCl	K-40	585	17	51	15	0,75

No Wait Time Required for Air Filter Analysis (if looking for EC)

Low energy beta aerosols (up to Co-60) can be detected immediately after removing the filter from the air sampler!



Note: „BETA" rate includes Rn/Th – alpha particles

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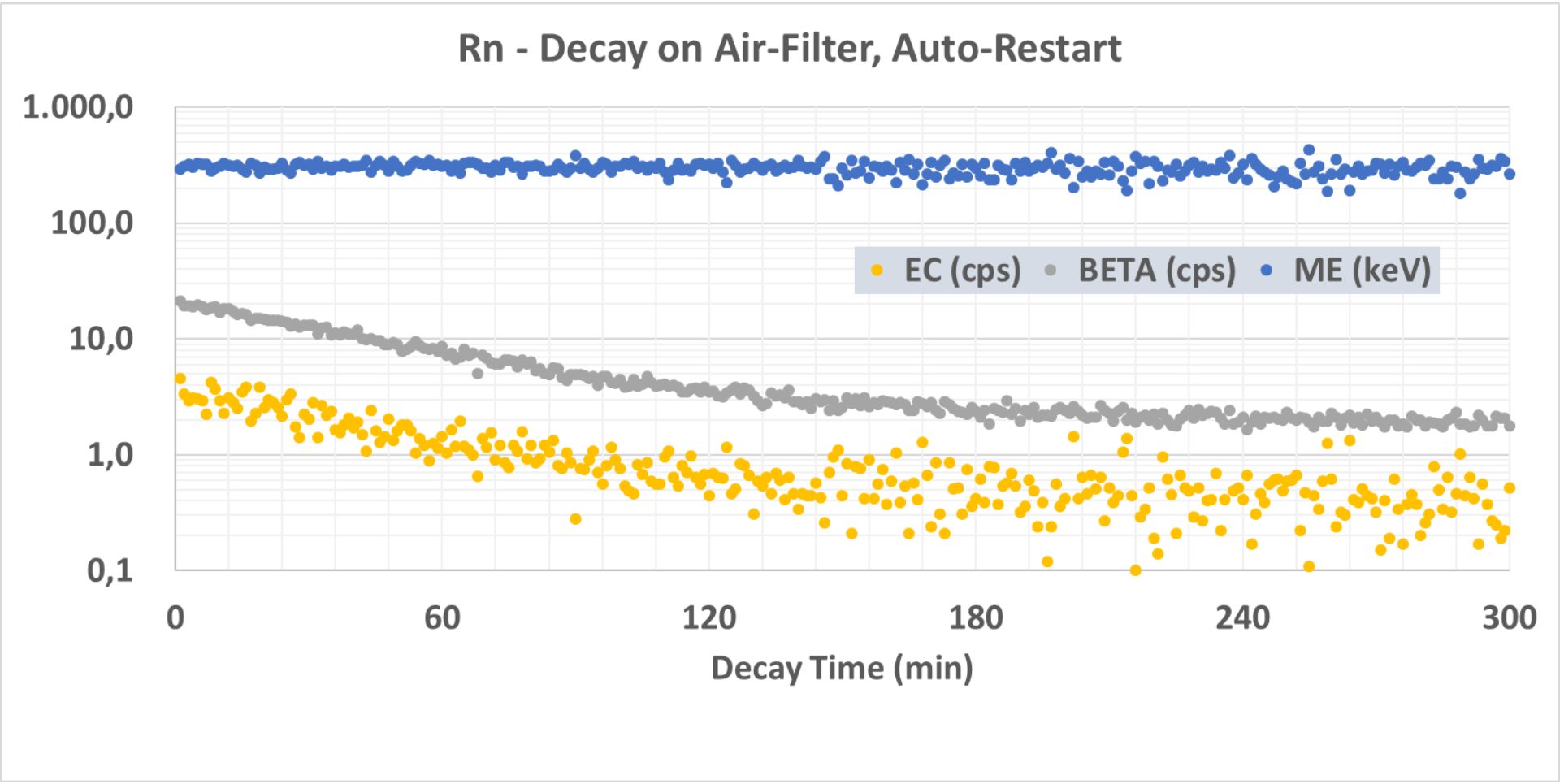
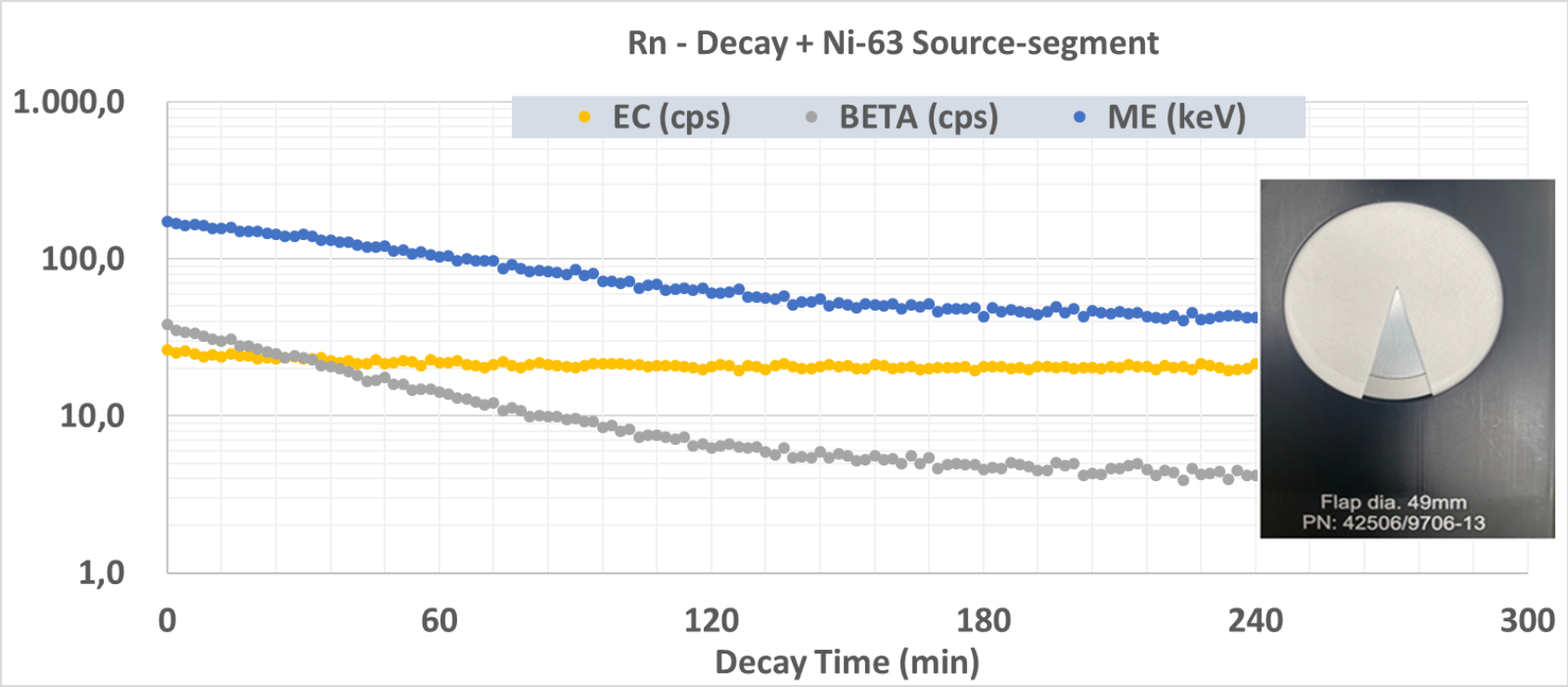
Net Count Rates (cps) & Mean Energy (keV) on Air Filter



Note: Beta energy measuring range is limited to app. 300 keV due to the thin scintillator

Experiment: Simulated Ni-63 Airborne Contamination

Filter paper was loaded for 8 h with 8 m³/h, then filter paper (with a segment cut off) was placed on top of a Ni-63 check source ➔ We observe an continuous decrease of the high energy contribution (BETA(cps), ME (keV) from Rn-progeny, while the Ni-63 contamination is immediately visible.



<u>Ni-63 Detection-Improvement on air filters over BA-Mode</u>:

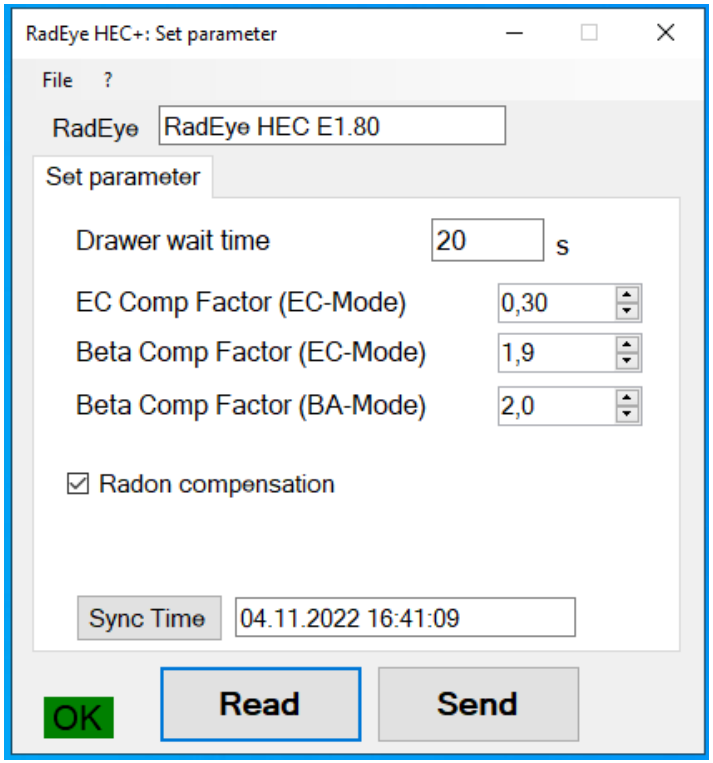
a) Efficiency for Ni-63 = 10 higher

b) 8 x lower interfering count rate from Rn – Progeny

➔ 80 times less interference relative to activity

Outlook: Tentative new Firmware with Rn-Compensation

A firmware enhancement is planned (not yet completed/released), so that Rn-compensated count rates are displayed on the info page after the end of the measurement. Rn-compensation factors can be set with a small PC-tool, for both BA and EC-mode:



The EC-compensation factor is very small and therefore the systematic and statistical influence of the (high energy) Rn-progeny on the filter is minimal. See slide 25 and 26.

The Beta-compensation factor in the EC-mode is just slightly lower than in the BA-mode.

Outlook: Specially doped* Lu2O3 Testadapter for Training

450 Bq Lu-176 simulates app.

15 Bq Co-60
15 Bq Cs-137

100 Bq Ni-63* (or 100 kBq H-3 check source)

*) radioluminescense

Note:
This is **not** a commercially available product (yet). This testadapter was used to generate the following screen shots of the optional Rn-compensation in a future firmware version of the RadEye HEC+.

Fresh Air Filter (Screen Shots of Planned Option)

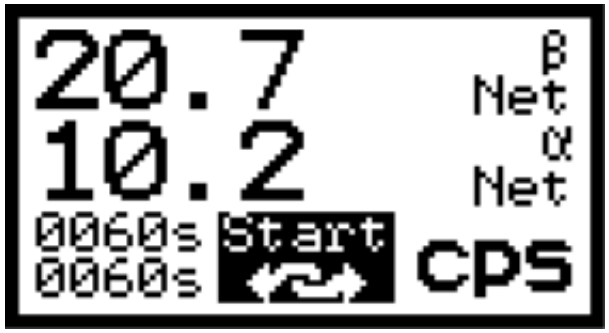
EC

Standard display, unchanged

info display, modified

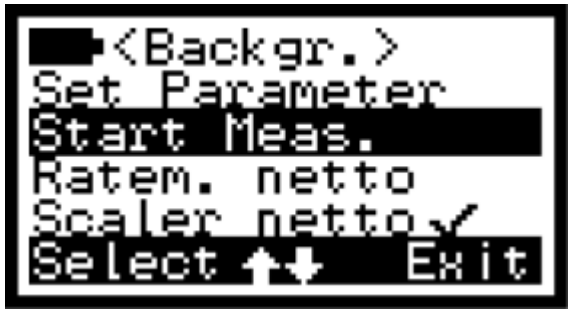
BA

Standard display, unchanged



info display, new

„Netto“ tagged or untagged ?



Gross „Ratem.“ (= „netto“ untagged) can be used for quick localisation of best positioning and orientation of the instrument (lowest background). „Scaler“ should be set to „netto“ for best energy calculation (after background learning) near background level. „Netto“ tagged or untagged is irrelevant for Elevated Contamination.

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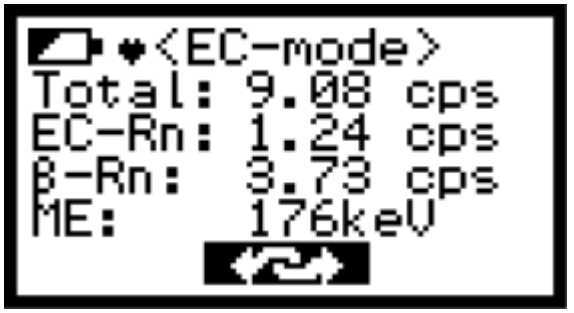
Tutorial: 9 g Lu2O3 special adapter (with Ni-63/H-3 Simulation)

9g Lu2O3 with optical activator

50 % cover (fresh filter paper)



Info page with Rn-compensation active (tentative new firmware)

100 % cover (filter paper shields simulated H-3 or Ni-63 completely)

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Good Practice and What to Avoid

- Do not leave Slide half open
- Charge HEC+ at least monthly
- Remove fuse if HEC+ is not in use for > 1 month
- Do not insert fresh filter material that can release H-3 Vapor
- Make sure that the filter is flat (pressed down by flap)
- Avoid (if possible) operation in bright sun light (Eventually extend wait time to 30 s)

Conclusion / Takeaway

RadEye HEC+ is a light-weight Beta/Alpha-sample changer with excellent alpha efficiency and low gamma sensitivity.

The new EC-mode allows insitu beta energy analysis and extremely sensitive detection and measurement of e.g. Ni-63.

For activity related measurement of H3-contamination field experience and data needs yet to be gathered, but H3-contamination can definitively be **detected** at the work place without delay and cost of LSC-analysis in a laboratory.

Feed back is highly appreciated:

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